

# Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/GB05/001141

International filing date: 18 March 2005 (18.03.2005)

Document type: Certified copy of priority document

Document details: Country/Office: GB  
Number: 0406336.8  
Filing date: 19 March 2004 (19.03.2004)

Date of receipt at the International Bureau: 13 June 2005 (13.06.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)



World Intellectual Property Organization (WIPO) - Geneva, Switzerland  
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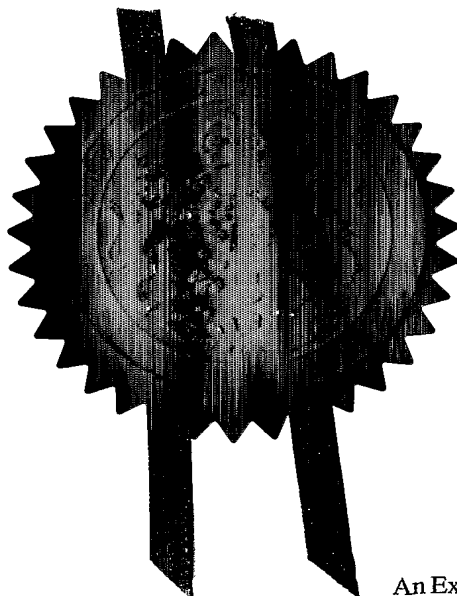
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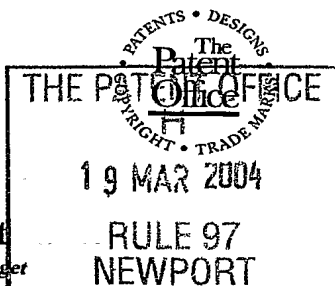
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1. Your reference P32863-/MGO/JDB

2. Patent application number 0406336.8  
(The Patent Office will fill this part in)

19 MAR 2004

3. Full name, address and postcode of the or of each applicant (underline all surnames)  
Subsea 7 (UK)  
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Subsea 7 BV  
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Patents ADP number (if you know it)

8550597001

875 298 2001

If the applicant is a corporate body, give the country/state of its incorporation

UNITED KINGDOM Netherlands

ET 1111  
2.3.05

4. Title of the invention "Apparatus and Method"

5. Name of your agent (if you have one) Murgitroyd & Company  
"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)  
165-169 Scotland Street  
Glasgow  
G5 8PL

Patents ADP number (if you know it) 1198015

6. Priority: Complete this section if you are declaring priority from one or more earlier patent applications, filed in the last 12 months.

Country	Priority application number (if you know it)	Date of filing (day / month / year)
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7. Divisionals, etc: Complete this section only if this application is a divisional application or resulted from an entitlement dispute (see note f)

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8. Is a Patents Form 7/77 (Statement of inventorship and of right to grant of a patent) required in support of this request?

Yes

Answer YES if:

- a) any applicant named in part 3 is not an inventor, or
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# Patents Form 1/77

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Continuation sheets of this form	-
Description	34 ✓
Claim(s)	-
Abstract	-
Drawing(s)	3 + 3 <i>Jim</i>

10. If you are also filing any of the following, state how many against each item.

Priority documents	-
Translations of priority documents	-
Statement of inventorship and right to grant of a patent (Patents Form 7/77)	-
Request for a preliminary examination and search (Patents Form 9/77)	-
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Signature(s)

*Murphy & Co*  
MURPHY & COMPANY

Date 18/03/04

12. Name, daytime telephone number and e-mail address, if any, of person to contact in the United Kingdom

James D Brown  
01224 706616

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1     "Apparatus and Method"

2

3     The present invention relates to apparatus and a  
4     method that are particularly, but not exclusively,  
5     suited for deep-water heave compensation.

6

7     It is common in the marine industry for loads to be  
8     lowered from a surface vessel to the seabed. The  
9     surface vessel is typically provided with a winch or  
10    crane that is capable of lowering a load to the  
11    seabed, or raising a load therefrom. As the vessel  
12    floats on the sea, the wave action of the sea causes  
13    vessel motions, which in turn cause motion of the  
14    top end of the lowering cable or rope. In  
15    particular, vertical motion of the top end of the  
16    cable or rope translates to an undesirable vertical  
17    motion of the suspended load.

18

19    Unwanted vertical motion of the suspended load  
20    creates two problems in the marine industry.  
21    Firstly, relative motion between the load and the  
22    surrounding water introduces additional loads into

1 the system. Secondly, the uncontrolled vertical  
2 motion of the suspended load makes it difficult for  
3 an operator to be confident of positioning a load on  
4 the seabed, or other landing site, in a safe and  
5 damage-free manner. Thus, the load may be set down  
6 too heavily causing damage thereto.

7  
8 Heave compensated cranes and winches are the common  
9 solution to these problems. A conventional heave  
10 compensated winch or crane includes a motion  
11 reference unit that monitors the motion of the  
12 vessel. The motion of the vessel is translated to  
13 the point from which the load and lowering rope are  
14 suspended, and thus the output from the motion  
15 reference unit can be used to monitor the motion of  
16 the point of suspension. The output from the motion  
17 reference unit forms a feedback loop to the control  
18 system that drives the winch or crane so that the  
19 vertical motion of the vessel caused by the waves  
20 can be compensated for. As a result, the point from  
21 which the load and lowering rope are suspended  
22 becomes nearly stationary. In practice however, it  
23 is not generally possible to compensate entirely for  
24 the heave of the vessel, and thus there is normally  
25 some small residual motion at the load. This motion  
26 is usually within acceptable limits for handling  
27 loads.

28  
29 These conventional heave compensation systems  
30 generally work well in relatively shallow water  
31 (depths up to around a few hundred metres). This is  
32 because the lift wire is relatively short, and the

1 wire acts as a stiff spring. The magnitude of any  
2 resonance in the system is therefore minimal and  
3 easily accommodated for by the operator of the winch  
4 or crane.

5  
6 However, when working at depths beyond this, further  
7 difficulties arise, in particular, the elasticity  
8 inherent in the long hoist cable. This can induce  
9 motions in the load that are not directly related to  
10 the vessel motion and therefore load control based  
11 solely on the measurement of the latter is no longer  
12 adequate. Even in relatively shallow depths,  
13 resonant behaviour can still become a problem if a  
14 conventional (steel) lift wire cannot be used for  
15 whatever reason (e.g. for operational reasons, a  
16 fibre lift wire must be used).

17  
18 According to an initial aspect of the present  
19 invention, there is provided load movement control  
20 system for a winch or crane system located on a  
21 vessel, the winch or crane system including a lift  
22 wire, the load movement control system comprising:-

- 23 a) a control means to permit an operator to  
24 instruct the winch or crane system to at least  
25 raise, hold or lower the lift wire;
- 26 b) a vessel motion detection means for  
27 detecting heave acting upon the vessel and winch or  
28 crane system;
- 29 c) lift wire resonance prevention means for  
30 measuring and/or predicting the tension in the lift  
31 wire; and



1           a control device capable of receiving outputs  
2 from the a) operator control means, b) vessel motion  
3 detection and c) lift wire resonance prevention  
4 means means and controlling the winch or crane  
5 system in response to said outputs.

6  
7 According to the initial aspect of the present  
8 invention, there is also provided a method of  
9 controlling the movement of a load raised or lowered  
10 by a winch or crane system provided on a vessel, the  
11 winch or crane system including a lift wire, the  
12 method comprising the steps of:-

13           a) providing an output from an operator control  
14 means which indicates if an operator instructs  
15 raising, holding or lowering of the lift wire;

16           b) providing an output indicative of heave  
17 acting upon the vessel and winch or crane system;

18           c) providing an output indicative of a  
19 prediction and/or measurement of resonance generated  
20 in the lift wire; and

21           d) adjusting the pay out or recovery of the  
22 lift wire in response to the said outputs a) to c).

23  
24 Typically, the method and apparatus according to the  
25 initial aspect comprises providing a control device  
26 including a computation means.

27  
28 Optionally, the control device is further capable of  
29 receiving an output from a load movement device and  
30 is optionally further capable of controlling the  
31 winch or crane system in response to said output.  
32

1 According to a first aspect of the present  
2 invention, there is provided heave compensation  
3 apparatus for a winch or crane system, the winch or  
4 crane system including a lift wire, the apparatus  
5 comprising:-

6 a lift wire tension measuring device for  
7 measuring the tension in the lift wire;

8 and a control device capable of receiving an  
9 output from the lift wire tension measuring device  
10 and controlling the winch or crane system according  
11 to the changes in tension in the lift wire, so as to  
12 stabilise the load.

13

14 According to the first aspect of the present  
15 invention, there is also provided a method of heave  
16 compensation for a winch or crane system, the winch  
17 or crane system including a lift wire, the method  
18 comprising the steps of:-

19 measuring the tension in the lift wire; and  
20 adjusting the pay out or recovery of the lift  
21 wire to compensate for the changes in the measured  
22 tension.

23

24 In the first aspect, the apparatus optionally  
25 includes a load motion measurement device for  
26 measuring the motion of the load, and the control  
27 device is capable of receiving an output from the  
28 load motion measurement device and controlling the  
29 winch or crane system according to the movement of  
30 the load.

31

1 Also in the first aspect, where the winch or crane  
2 system is provided on a vessel, the apparatus  
3 optionally includes a vessel motion measurement  
4 device for measuring the motion of the vessel, and  
5 the control device is capable of receiving an output  
6 from the vessel motion measurement device and  
7 controlling the winch or crane system according to  
8 the movement of the vessel.

9  
10 Also in the first aspect, where the winch or crane  
11 system is provided on a vessel, the apparatus  
12 preferably comprises a lift wire distance  
13 measurement device which measures the length of lift  
14 wire that has been paid out.

15  
16 According to a second aspect of the present  
17 invention, there is provided heave compensation  
18 apparatus for a winch or crane system, the winch or  
19 crane system including a lift wire for attachment to  
20 a load, the apparatus comprising:-

21 a load motion measurement device for measuring  
22 the motion of the load, and a control device capable  
23 of receiving an output from the load motion  
24 measurement device and controlling the winch or  
25 crane system according to the movement of the load,  
26 so as to stabilise the load.

27

28 According to the second aspect of the present  
29 invention, there is also provided a method of heave  
30 compensation for a winch or crane system, the winch  
31 or crane system including a lift wire, the method  
32 comprising the steps of:-

1 monitoring the movement of a load suspended by  
2 the lift wire; and

3 adjusting the pay out or recovery of the lift  
4 wire to compensate for the movement of the load.  
5

6 Also in the second aspect, where the winch or crane  
7 system is provided on a vessel, the apparatus  
8 optionally includes a vessel motion measurement  
9 device for measuring the motion of the vessel, and  
10 the control device is capable of receiving an output  
11 from the vessel motion measurement device and  
12 controlling the winch or crane system according to  
13 the movement of the vessel.  
14

15 Also in the second aspect, where the winch or crane  
16 system is provided on a vessel, the apparatus  
17 preferably comprises a lift wire distance  
18 measurement device which measures the length of lift  
19 wire that has been paid out.  
20

21 Also in the second aspect, where the winch or crane  
22 system is provided on a vessel, the apparatus  
23 optionally includes a lift wire tension measuring  
24 device for measuring the tension in the lift wire.  
25

26 According to a third aspect of the present  
27 invention, there is provided heave compensation  
28 apparatus for a winch or crane system, the winch or  
29 crane system including a lift wire for attachment to  
30 a load, the apparatus comprising:-

31 a lift wire distance measurement device which  
32 measures the length of lift wire that has been paid

1 out, and a control device capable of receiving an  
2 output from the lift wire distance measurement  
3 device and controlling the winch or crane system  
4 according to the distance measured, so as to  
5 stabilise the load.

6  
7 According to the third aspect of the present  
8 invention, there is also provided a method of heave  
9 compensation for a winch or crane system, the winch  
10 or crane system including a lift wire, the method  
11 comprising the steps of:-

12 measuring the length of lift wire paid out; and  
13 adjusting the pay out or recovery of the lift  
14 wire to stabilise the load.

15  
16 According to a fourth aspect of the present  
17 invention, there is provided heave compensation  
18 apparatus for a winch or crane system, the winch or  
19 crane system being provided on a vessel and  
20 including a lift wire for attachment to a load, the  
21 apparatus comprising:-

22 a vessel motion measurement device for  
23 measuring the motion of the vessel;

24 and a control device capable of receiving an  
25 output from the vessel motion measurement device and  
26 controlling the winch or crane system according to  
27 the movement of the vessel, so as to stabilise the  
28 load;

29 wherein the apparatus further comprises at  
30 least one of:-

31 a) a lift wire tension measuring device for  
32 measuring the tension in the lift wire;

1           b) a lift wire distance measurement device  
2 which measures the length of lift wire that has been  
3 paid out; and

4           c) a load motion measurement device for  
5 measuring the motion of the load.

6  
7 According to the fourth aspect of the present  
8 invention, there is also provided a method of heave  
9 compensation for a winch or crane system provided on  
10 a vessel, the winch or crane system including a lift  
11 wire, the method comprising the steps of:-

12 monitoring the motion of the vessel and controlling  
13 the winch or crane system according to the movement  
14 of the vessel by adjusting the pay out or recovery  
15 of the lift wire to stabilise the load;

16 and further comprising at least one of the  
17 following steps:-

18           a) measuring the tension in the lift wire;  
19           b) measuring the length of lift wire that has  
20 been paid out; and  
21           c) measuring the motion of the load.

22

23 Preferably, the lift wire tension measuring device  
24 is capable of monitoring changes in the tension on  
25 the lift wire.

26

27 The apparatus typically includes a rotatable member  
28 that diverts the lift wire towards the seabed. The  
29 rotatable member, which may be a sheave, is  
30 typically rotatably mounted on a frame by the load  
31 measuring device, which may be a load pin.

32

1 The lift wire tension measuring device typically  
2 monitors the change in tension on the load pin.  
3 Thus, the changes in the tension in the lift wire  
4 can be determined by monitoring the change in  
5 tension on the load pin.

6  
7 In an alternative embodiment, the lift wire tension  
8 measuring device can be configured to measure the  
9 in-line loads in the lift wire. For example, the  
10 load measuring device can be coupled to the winch or  
11 crane system so that the tension in the lift wire  
12 can be monitored directly (e.g. using load cells or  
13 the like located at the point where the winch is  
14 secured to the vessel).

15  
16 The vessel motion measurement device typically  
17 comprises a motion reference unit. The load motion  
18 measurement device typically comprises a motion  
19 reference unit which is optionally coupled to the  
20 load.

21  
22 In certain embodiments, the load motion measuring  
23 device is electrically coupled to the control  
24 device. In alternative embodiments, the load motion  
25 measuring device is coupled to the control device  
26 using fibre optics or any other transmission system.

27  
28 The control device typically comprises a control  
29 computer. The control device is typically coupled  
30 to the drive unit for the winch or crane system.  
31 Thus, the control device can, in addition to  
32 controlling the pay out and recovery of the lift

1 wire in response to inputs from the human operator,  
2 the control device can also control the pay out and  
3 recovery of the lift wire in response to the output  
4 from any of the following:-

5 the lift wire tension measuring device; and/or  
6 the vessel motion measurement device; and/or  
7 the load motion measurement device; and/or  
8 a lift wire distance measurement device.  
9

10 For example, where the output of the lift wire  
11 tension measuring device indicates that the tension  
12 in the lift wire is increasing, the control device  
13 typically pays out wire in order to reduce the  
14 tension. Where the output of the lift wire tension  
15 measuring device indicates that the tension in the  
16 lift wire is decreasing, the control device  
17 typically recovers wire in order to increase the  
18 tension. The sequence of pay out and recovery  
19 operations typically attenuates the tension in the  
20 lift wire. Alternatively, or additionally, the  
21 sequence of pay out and recovery operations  
22 typically attenuates the stretch of the lift wire.  
23 This has the advantage that excess energy in the  
24 crane or winch system is avoided, which in turn  
25 leads to a more stable load.  
26

27 For example, where the output of the load motion  
28 reference unit indicates that the load is moving so  
29 that the tension in the lift wire would increase,  
30 the control device typically pays out wire in order  
31 to maintain the tension at a level necessary to  
32 prevent such load movement. Where the output of the



1 load motion reference unit indicates that the load  
2 is moving so that the tension in the lift wire would  
3 decrease, the control device typically recovers wire  
4 in order to maintain the tension at a level  
5 necessary to prevent such load movement. The  
6 increase or decrease in tension typically avoids any  
7 excess energy in the system, thereby stabilising the  
8 load and avoiding any unwanted movement thereof.

9  
10 Alternatively, or additionally, where the output of  
11 the load motion reference unit indicates that the  
12 load is moving so that the stretch of the lift wire  
13 would increase, the control device typically pays  
14 out wire in order to maintain the stretch at a level  
15 necessary to prevent such load movement. Where the  
16 output of the load motion reference unit indicates  
17 that the load is moving so that the stretch of the  
18 lift wire would decrease, the control device  
19 typically recovers wire in order to maintain the  
20 stretch at a level necessary to prevent such load  
21 movement. The increase or decrease in stretch  
22 typically avoids any excess energy in the system,  
23 thereby stabilising the load and avoiding any  
24 unwanted movement thereof.

25  
26 The control device is typically provided with a  
27 plurality of inputs. A first input comprises a  
28 signal from a lift wire distance measurement device.  
29 The lift wire distance measurement device typically  
30 measures the length of lift wire that has been paid  
31 out. In certain embodiments, the length of wire  
32 paid out is used to determine the elasticity of the

1     given length of the lift wire. The given length of  
2     the lift wire typically forms a second input to the  
3     control device. The control device typically  
4     calculates the elasticity of the lift wire from the  
5     length of wire paid out, typically by reference to  
6     its elasticity characteristics. An operator  
7     typically inputs this reference data into the  
8     control device before commencing a lift operation.

9  
10    A third input comprises a signal from a vessel  
11    motion reference unit provided on the vessel. Thus,  
12    the control device is provided with an indication of  
13    the movement of the vessel.

14  
15    In certain embodiments, an effective mass of the  
16    load typically forms an input, such as a fourth  
17    input, to the control computer. The effective mass  
18    of the load typically comprises a mass of the load  
19    itself, an added mass, and drag loads. The mass of  
20    the load itself is typically deduced from the weight  
21    and buoyancy of the load. The added mass of the  
22    load is typically deduced from the amount of water  
23    that is required to be moved with the load. The  
24    drag load is typically deduced from the drag  
25    characteristics of the load in the direction of  
26    motion thereof. An operator typically inputs this  
27    reference data into the control device before  
28    commencing a lift operation.

29  
30    In certain embodiments, a vessel motion reference  
31    unit can optionally be provided, to measure vessel  
32    movements. In this embodiment, an output from the

1 vessel motion reference unit typically forms an  
2 input, such as a fifth input, to the control  
3 computer.

4  
5 In certain embodiments, a load measuring device,  
6 which may be in the form of a lift wire tension  
7 measurement device, can optionally be provided. In  
8 this embodiment, an output from the lift wire  
9 tension measurement device typically forms an input,  
10 such as a sixth input, to the control computer.

11  
12 In the method according to the first aspect of the  
13 present invention, the step of monitoring changes in  
14 the tension applied to the lift wire typically  
15 comprises the step of receiving an output from a  
16 lift wire tension measurement device indicative of  
17 the changes in the tension.

18  
19 Also in the method according to the first aspect of  
20 the present invention, the lift wire is typically  
21 paid out when the tension in the lift wire  
22 increases, and the lift wire is typically recovered  
23 when the tension in the lift wire decreases, in  
24 order to attenuate natural resonance effects of the  
25 lift wire.

26  
27 In the method according to the fourth aspect of the  
28 present invention, the step of monitoring movement  
29 of a load suspended from the lift wire typically  
30 comprises the step of receiving an output from a  
31 load motion reference device that is indicative of  
32 the movement of the load.

1

2 Also in the method according to the fourth aspect of  
3 the present invention, the lift wire is typically  
4 paid out when the movement of the load is such that  
5 the tension in the lift wire increases, and the lift  
6 wire is typically recovered when the movement of the  
7 load is such that the tension in the lift wire  
8 decreases.

9

10 The apparatus is particularly suited for use on  
11 board vessels, such as seagoing vessels, but is not  
12 limited to such use.

13

14 Embodiments of the present invention shall now be  
15 described, by way of example only, and with  
16 reference to the accompanying drawings, in which: -

17 Fig. 1 is a schematic representation of a  
18 vessel provided with a particular embodiment of  
19 heave compensation apparatus;

20 Fig. 2 is a schematic representation of a  
21 vessel provided with an alternative embodiment  
22 of heave compensation apparatus; and

23 Fig. 3 is a block diagram of outline control  
24 requirements for embodiments of the present  
25 invention.

26

27 Referring now to the drawings, Fig. 1 schematically  
28 shows an exemplary embodiment of heave compensation  
29 apparatus provided on a surface vessel 10. In this  
30 embodiment, the vessel 10 is provided with a winch  
31 12 to facilitate lowering a load 14 to a particular

1 depth in the water such as the seabed (not shown) or,  
2 raising the load 14 therefrom.

3

4 It should be noted that the term "seabed" as used  
5 herein will be understood to refer to any underwater  
6 bed (e.g. a lake bed, river bed etc.).

7 It should also be noted that the load 14 need not be  
8 lowered direct to the seabed. In some cases, the  
9 load 14 may be lowered onto or raised from other  
10 underwater locations, for example apparatus and  
11 equipment such as wellheads, manifolds and the like.

12

13 Also, the particular embodiment described herein  
14 refers to the use of a winch 12. However, a crane  
15 or other lifting apparatus could be provided in  
16 place of the winch 12, and embodiments of the  
17 present invention can be used with these and other  
18 variations also.

19

20 The load 14 is attached to the winch 12 using a lift  
21 wire 16. The lift wire 16 is conventionally reeled  
22 onto a winch drum 18 forming part of the winch 12.

23 The lift wire 16 is paid out and recovered by  
24 turning the winch drum 16, which is typically  
25 accomplished using a winch drive 20. In certain  
26 embodiments, a tension control device can optionally  
27 be interposed between the winch 12 and an over-  
28 boarding sheave 22.

29

30 The lift wire 16 can take many different forms, and  
31 need not be a steel wire since the lift wire 16 may  
32 comprise steel cable, braided cable, rope, fibre

1 rope etc. The term "lift wire" as used herein is to  
2 be understood to refer to all of these and other  
3 variations.

4  
5 The skilled reader will realise that stabilising the  
6 load 14 in accordance with embodiments of the  
7 present invention requires that, at any given time,  
8 the crane or winch 12 control system 28 can  
9 determine the potential effects of a mix of operator  
10 commands, vessel motion and lift wire 16 resonance  
11 on the position of the load 14 relative to where the  
12 operator requires the load 14 to be positioned. The  
13 control system 28 described herein can thus command  
14 the winch 12 to react (i.e. hold/pay out/recover  
15 lift wire 16) so as to move the load 14 as commanded  
16 by the operator, whilst simultaneously compensating  
17 for vessel 10 motion and inhibiting lift wire 16  
18 resonance, thus enabling full control of the load 14  
19 at all times.

20  
21 Optionally, the data available for the operation of  
22 the control system 28, can be augmented by  
23 information on the actual movement of the load 14 by  
24 means of the output of a load motion reference unit  
25 154.

26  
27 The skilled reader will also realise that such a  
28 control system 28 will use adaptive/predictive  
29 control techniques.

30  
31 The process of command, control, and stabilisation  
32 outlined above, comprises a mix of inputs and

1 outputs depending on the situation being addressed  
2 at any one time (e.g. the vessel 10 may be moving  
3 down requiring lift wire 16 to be recovered, whilst  
4 the load 14 is moving down requiring lift wire 16 to  
5 be paid out to avoid resonance). The control  
6 process is however made up of four basic elements  
7 which are applied in varying ways by software  
8 provided in the control system 28 as the situation  
9 demands. These are:

10

11 **Wire Resonance Control:** lift wire 16 paid  
12 out/recovered/held as determined by the control  
13 system 28 software using inputs from the wire  
14 tension 24 and payout 26 transducers. The  
15 underlying control aim is to minimise lift wire 16  
16 tension above or below that imposed by the need to  
17 support the load 14 itself (i.e. lift wire 16  
18 stretch) so as to inhibit a build up of spring  
19 energy (i.e. resonant effects) in the lift wire 16.

20

21 **Compensation for Vessel Motion:** lift wire 16 paid  
22 out/recovered/held as determined by the control  
23 system 28 software using vessel 10 motion inputs  
24 from a vessel Motion Reference Unit 38. The  
25 underlying control aim is to minimise unwanted or  
26 uncommanded load 14 movement.

27

28 **Compensation for Load Movement (optional):** lift  
29 wire 16 paid out/recovered/held as determined by the  
30 control system 28 software using load motion inputs  
31 from a load Motion Reference Unit. The underlying

1 control is again to minimise unwanted or uncommanded  
2 load 14 movement.

3

4 **Operator Commands:** lift wire 16 paid out/recovered/  
5 held as directed by the operator. The control  
6 system 28 software will integrate these particular  
7 operator commands with those needed to meet the load  
8 stabilisation demands as described above, so that  
9 the load 14 is moving as directed, but is under full  
10 operator control at all times, largely independent  
11 of the effects of vessel 10 motion, or lift wire 16  
12 resonance.

13

14 The arrangement of embodiments in accordance with  
15 the various aspects of the present invention will  
16 now be described in more detail.

17

18 The lift wire 16 extends from the winch 12 over the  
19 sheave 22, which diverts the wire 16 towards the  
20 seabed. The sheave 22 is conventional in the art  
21 and is typically a pulley wheel with a grooved rim,  
22 mounted in a frame (not shown) located on the vessel  
23 10. The sheave 22 is mounted on the frame by a load  
24 pin 24 so that the sheave 22 may rotate relative to  
25 the frame if desired.

26

27 A wire length indicator 26 (e.g. an encoder) is  
28 provided in the path of the lift wire 16, and is  
29 typically formed by an idler sheave that is rotated  
30 with the movement of the lift wire 16 as it is paid  
31 out and recovered. In some embodiments, the  
32 indicator 26 may form part of the winch 12. The



1 wire length indicator 26 is typically used to inform  
2 an operator of the winch system of the approximate  
3 length of wire 16 that has been paid out (e.g. the  
4 approximate length of the lift wire 16 to the load  
5 14). The output of the indicator 26 also forms an  
6 input to a control computer 28, the output being  
7 used to calculate the elasticity of the length of  
8 the paid out wire 16. The output can be coupled  
9 direct to the control computer 28 if the output of  
10 the indicator 26 and the input to the control  
11 computer 28 are compatible.  
12

13 The control computer 28 is used to control the winch  
14 drive 20 and thus the rate at which the lift wire 16  
15 is paid out and recovered. The control computer 28  
16 is electrically linked to the winch drive 20 by a  
17 cable 30 or other transmission system, and can  
18 respond automatically to control operation of the  
19 winch 12 in response to certain variables including  
20 an output from the wire length indicator 26 (via a  
21 cable 32) or from operator input at a control  
22 console 34 electrically coupled to the control  
23 computer 28 via a cable 36. The control console 34  
24 is typically located on-board the vessel 10.  
25 Accordingly, if the operator pushes a lever, button  
26 or other suitable man-machine interface (MMI),  
27 provided on the control console 34, the control  
28 computer accepts such commands and instructs the  
29 winch drive 20 to pay out or reel in the lift wire  
30 16 as instructed.  
31

1 The vessel 10 can be provided with a conventional  
2 Motion Reference Unit (MRU) 38 that provides  
3 feedback to the control computer 28 (via cable 40)  
4 so that the heave motion of the vessel 10 can be  
5 compensated for. The MRU 38 typically measures the  
6 motion of the vessel 10 relative to an average datum  
7 and provides, generally in a processed form, control  
8 signals that drive a heave compensator (not shown)  
9 in the correct direction by the correct amount. The  
10 heave compensation of the winch 12 overlays the  
11 normal input commands from an operator to lift,  
12 lower or hold the load 14. Accordingly, the motion  
13 experienced by the load 14 due to the heave motion  
14 experienced by the heave of the vessel 10 can be  
15 compensated for, as is conventional in the art.

16  
17 Optionally, the control computer 28 can be provided  
18 with input from a load motion sensor unit (not shown  
19 but could be a further MRU) attached to the load 14,  
20 as indicated by optional cable 42. This latter  
21 embodiment is discussed in more detail with  
22 reference to Fig. 2.

23  
24 In the embodiment shown in Fig. 1, and in accordance  
25 with various aspects of the present invention, the  
26 motion of the load 14 can be detected by monitoring  
27 the forces applied at the load pin 24 of the sheave  
28 22 caused by the reactions of the load 14 to the  
29 applied vessel motion. The load at the load pin 24  
30 is typically monitored using a tension gauge so that  
31 the tension on the lift wire 16 caused by the  
32 reactions of the load 14 can be monitored at the

1 load pin 24. Monitoring the load at the load pin 24  
2 is convenient, but the invention is not limited to  
3 this embodiment only. The load at the top of the  
4 lift wire 16 can be monitored using any conventional  
5 means. Accordingly, the resonance effects  
6 experienced by the load 14 due to the elasticity in  
7 the lift wire 16 can also be compensated for (in  
8 addition to the conventional heave compensation  
9 which is also provided for).

10

11 The information from the gauge at the load pin 24 is  
12 fed to the control computer 28 via a cable 44. This  
13 has the advantage of monitoring the movement of the  
14 load 14 as manifested at the top of the lift wire  
15 16, thus giving the control computer 28 information  
16 about the dynamic state and responses of the winch  
17 system. The dynamic state and response of the winch  
18 system would include any resonant behaviour of the  
19 lift wire 16, particularly at increased depths, and  
20 the elasticity of the lift wire 16, which has an  
21 effect on the resonant behaviour of the lift wire  
22 16.

23

24 The control computer 28 generally requires  
25 information on the configuration of the winch  
26 system. For example, the mass of the load 14 would  
27 form an input to the control computer 28. The mass  
28 of the load 14 comprises three distinct components;  
29 the first is the mass of the load 14 itself, which  
30 can be deduced from the weight of the load 14; the  
31 second component is the added mass provided by the  
32 water around the load 14 that is required to be

1 moved in order for the load 14 to be moved; and the  
2 third component is the drag characteristics of the  
3 load 14 in the direction of the motion of the load  
4 14 - this is typically a function of the water plane  
5 area and surface area of the load 14 that is in  
6 contact with the sea in the direction of motion of  
7 the load 14. The mass, added mass and drag  
8 characteristics can be input by the winch operator  
9 using the control console 34. The control computer  
10 28 is generally provided with a man-machine  
11 interface (MMI), e.g. in the form of the console 34  
12 so that these, and any other required data, can be  
13 input to the computer 28.

14  
15 The control computer 28 can be provided with pre-  
16 loaded reference data (e.g. look-up tables or the  
17 like) detailing, for a range of conditions, certain  
18 characteristics (e.g. dynamic, spring, drag, damping  
19 etc.) of the vessel 10, the load 14, the lift wire  
20 16 and the winch system.

21  
22 The pre-lift operator inputs define the actual  
23 vessel, hoist system, load and any other pertinent  
24 parameters.

25  
26 The control computer 28 is provided with appropriate  
27 software that can take account of outputs relating  
28 to the mass of the load 14, the length of the lift  
29 wire 16 paid out as well as motions of the vessel 10  
30 and the behaviour of the heave compensation system.  
31 In certain embodiments, the control software can  
32 apply adaptive and/or predictive control techniques.

1 The control software takes all of the data that is  
2 input and uses it to generate some of the control  
3 parameters required to achieve compensation so that  
4 unwanted movement of the load 14 is compensated for,  
5 and in particular, monitors the spring  
6 characteristics of the winch system.

7  
8 The adaptive/predictive techniques built into the  
9 software facilitate comparison of the resultant  
10 movement of the load 14 from the commands of the  
11 operator with the actual movement of the load 14,  
12 and makes adjustments to the software parameters so  
13 that the compensation technique will "learn" and  
14 improve with use. For example, the pre-loaded data  
15 and operator inputs result from a number of  
16 different sources, each with inherent inaccuracies  
17 of varying degree, and the software can correct  
18 these parameters based on actual results. Other  
19 control techniques may also be used to predict the  
20 motion of the load 14.

21  
22 The elasticity of the lift wire 16 would form  
23 another input to the control computer 28, and this  
24 is deduced from the length of the lift wire 16 that  
25 is paid out, and also the wire spring  
26 characteristics or stiffness. The length of the  
27 wire 16 that has been paid out is fed to the  
28 computer 28 from the wire length indicator 26 via  
29 cable 32, and thus the elasticity of the wire 16 can  
30 be calculated in a known manner.

31

1 The control computer 28, using appropriate software,  
2 takes the inputs from the operator of the winch 12,  
3 and from the wire length indicator 26, the MRU 38  
4 and the load pin 24, and controls the movement of  
5 the winch 12 and thus the load 14 by paying out and  
6 recovering the lift wire 16 in order to compensate  
7 for the resonant behaviour of the system and motion  
8 of the vessel 10.

9  
10 When the operator of the winch 12 commands movement  
11 of the load 14 (e.g. by operation of a joystick  
12 provided on the control console 34), then the  
13 control computer 28 would provide for motion of the  
14 winch 12 by facilitating a sequence of pay out and  
15 recovery operations of the wire 16 so that the  
16 excess energy that would otherwise have been caused  
17 by movement of the load 14 is avoided, thus  
18 stabilising the load 14 in any operating condition  
19 at any depth. This would cause the position of the  
20 load 14 to be changed without introducing  
21 oscillations to the load 14. The stabilisation of  
22 the load 14 is applied whether the load 14 is  
23 intended to be held stationary, or is being lifted  
24 or lowered.

25  
26 At resonance of the wire 16 (i.e. when the lift wire  
27 16 extends to a length sufficient to cause resonant  
28 behaviour, the system monitors the tension on the  
29 wire 16 at the load pin 24, and the control computer  
30 28 commands the winch 12 to either pay out the wire  
31 16 when the tension thereon increases, or recover  
32 the wire 16 as the tension thereon decreases, in

1 order to stabilise the load 14 and is again applied  
2 whether the load 14 is intended to be held  
3 stationary or is being lifted or lowered. The  
4 increase and decrease in tension is due to the  
5 movement of the load 14 (and/or the vessel 10) that  
6 causes the lift wire 16 to extend or retract,  
7 depending upon the direction of movement of the load  
8 14 (and/or the vessel 10). The sequence of pay out  
9 and recovery avoids build-up of excess energy in the  
10 system and thus prevents a build-up in the motion of  
11 the load 14 (i.e. when the load 14 is being  
12 lowered). Additionally, or alternatively, the  
13 sequence of pay out and recovery avoids build-up of  
14 a deficit in the energy in the system and thus  
15 prevents a build-up in the motion of the load 14  
16 (i.e. when the load 14 is being lifted). This, in  
17 turn, effectively eliminates the resonant behaviour  
18 of the lift wire 16 and the load 14.

19

20 Thus, if the load 14 moves downwardly due to  
21 resonant behaviour of the lift wire 16, the wire 16  
22 is further stretched causing the tension on the load  
23 pin 24 to increase, and thus the winch 12 is  
24 actuated to pay out more wire 16 in order to  
25 compensate for the increase in tension caused by the  
26 downward movement of the load 14. Conversely, if  
27 the load 14 moves upwardly due to resonant behaviour  
28 of the lift wire 16, the wire 16 contracts and the  
29 tension on the load pin 24 decreases, and thus the  
30 winch 12 is actuated to recover more wire 16 in  
31 order to compensate for the decrease in the tension  
32 caused by the upward movement of the load 14.

1  
2 At the bottom (i.e. when the load 14 is near the  
3 seabed), the winch 12 is commanded to move the load  
4 14 in such a way as to lower the load 14 without  
5 causing vertical oscillations. This control is  
6 provided by monitoring the tension on the wire 16 at  
7 the load pin 24, and adjusting the pay out and  
8 recovery of the wire 16 as described above, whilst  
9 still lowering the load 14.

10  
11 Thus, monitoring of the load at the load pin 24  
12 provides an early indication of the movement of the  
13 load 14 due to resonant behaviour of the lift wire  
14 16 and the load pin data output can be fed back to  
15 the control computer 28, which in turn can then  
16 eliminate and/or attenuate the unwanted resonant  
17 movement.

18  
19 The control software facilitates the movement and  
20 position of the load 14 to be known and controlled  
21 more accurately in response to operator input,  
22 taking into account the dynamics of the winch system  
23 including the winch 12, the lift wire 16 and the  
24 suspended load 14, and the control software uses an  
25 adaptive control algorithm to achieve stabilisation  
26 of the load 14. The information provided by the  
27 gauge at the load pin 24 may be delayed due to the  
28 dynamics of the lift wire 16, but the software can  
29 be configured to compensate for the control of  
30 parameters (i.e. the tension in the lift wire 16)  
31 that may not be measured or monitored direct.  
32



1 Fig. 2 shows an alternative embodiment that is  
2 similar to Fig. 1. Like reference numerals have  
3 been used to designate like components, prefixed  
4 "1".

5  
6 In the Fig. 2 embodiment, a junction box 150 is  
7 provided on the vessel 110, and the cables 132, 140  
8 and 144 from the wire length indicator 126, the MRU  
9 138 and the load pin 124 are joined at the junction  
10 box 150. A two-way cable 152 provides two-way  
11 communication to and from the junction box 150 to  
12 the control computer 128. Thus, the inputs from the  
13 indicator 126, the MRU 138 and the load pin 124 are  
14 transferred to the control computer 128 via the  
15 cable 152. Control signals from the control  
16 computer 128 to the winch drive 120 are routed  
17 through the control cable 152, the junction box 150  
18 and the control cable 130.

19  
20 Also in the embodiment of Fig. 2, a load motion  
21 reference unit 154 is provided on the load 114.  
22 Thus, the load MRU 154 outputs a signal indicative  
23 of the motion of the load 114. The signal is  
24 conveyed to the control computer 128 via cable 142,  
25 junction box 150 and the cable 152.

26  
27 The cable 142 can be separate from the lift wire 116  
28 or integral therewith (e.g. by use of an umbilical).

29  
30 The signal from the load MRU 154 is used in place of  
31 (or as in Fig. 2 in addition to) information on the  
32 tension in the lift wire 116 to allow the control

1 computer 128 to compensate for the movement of the  
2 load 114 due to resonant behaviour of the lift wire  
3 116. Thus, if the load 114 moves downwardly due to  
4 resonant behaviour of the lift wire 16, as indicated  
5 by the load MRU 154 (and/or the load on the load pin  
6 124), the winch 112 is actuated to pay out more wire  
7 116 in order to compensate for the unwanted downward  
8 movement of the load 114. Conversely, if the load  
9 114 moves upwardly due to resonant behaviour of the  
10 lift wire 16, as indicated by the load MRU 154  
11 (and/or the load on the load pin 124), the winch 112  
12 is actuated to recover more wire 116 in order to  
13 compensate for the unwanted upward movement of the  
14 load 114.

15  
16 In this particular embodiment, the approach to  
17 resonance damping detects variations in the tension  
18 on the lift wire 116, and generally separates out  
19 the effects on the load 114 caused by resonance.  
20 The information from the indicator 126 and from the  
21 load MRU 154 are converted into adjustments of the  
22 wire length (e.g. to adjust the tension in the lift  
23 wire 116) so as to neutralise or dampen the  
24 resonance behaviour of the load 114. This keeps the  
25 load 114 stable as the strain energy in the lift  
26 wire 116 neither increases nor decreases (i.e. is  
27 not in excess or deficit), and consequently, cannot  
28 induce resonance in the load 114. The damping  
29 process overlays the basic operator commands to the  
30 winch 112 (i.e. to lift, lower or hold the load  
31 114).

32

1 In general, it is preferable for the system to take  
2 account of all the ongoing influences on rope  
3 tension and the position of the load, including, but  
4 not limited to, resonance, heave compensation  
5 actions and operator commands to lift, lower and  
6 hold the load 114. The software on the control  
7 computer 128 processes data obtained from these  
8 influences to prevent unwanted movement of the load  
9 114 when it is being held, lifted or lowered. This  
10 leads to the load 114 moving in the way anticipated  
11 and expected by the operator, without any undue  
12 influence from the motion of the vessel 110 or  
13 resonance of the lift wire 116.

14

15 The Fig. 2 embodiment has the advantage that it  
16 reduces the requirement for predictive/adaptive  
17 capabilities in the software as it provides  
18 information on the actual load movement versus the  
19 anticipated load movement using the load MRU 154.

20

21 Fig. 3 shows in block diagram the inputs into the  
22 control computer 28 for two different scenarios of  
23 operation:-

24 Depth =  $N \times 10^2$  metres of water (e.g. up to a  
25 few hundred meters of water depth) and is indicated  
26 by reference numeral 71; and

27 Depth =  $N \times 10^3$  metres of water (e.g. thousands  
28 of meters of water depth) and is indicated by  
29 reference numeral 73.

30

31 In shallower water (i.e. depth 71) only the operator  
32 commands (lift or lower) and the vessel heave motion

1 reference unit inputs 38; 138 are required by the  
2 control computer because there are no apparent  
3 resonant effects exhibited by the lift wire 16.  
4 Thus the system in this mode of operation can be  
5 considered to be operating like a conventional heave  
6 compensation system since no resonance effects due  
7 to elasticity of the lift wire 16 need be  
8 compensated for since they are so minimal or non-  
9 apparent.

10

11 However, in deeper water (i.e. depth 73) the  
12 operator commands (lift or lower) and the vessel  
13 heave motion reference unit inputs 38; 138 are input  
14 into the control computer along with the additional  
15 inputs shown in Fig. 3 in order that the control  
16 computer can attenuate the resonant effects  
17 exhibited by the lift wire 16.

18

19 Embodiments of the present invention offer  
20 advantages over conventional heave compensation  
21 techniques, in that the load can be stabilised in  
22 any operating condition at any depth.

23

24 Certain embodiments of the present invention extend  
25 the function of the control system for the winch or  
26 crane so that the problems associated with the  
27 resonant behaviour and/or oscillating response of  
28 the suspended load are minimised or overcome.

29

30 Certain embodiments of the present invention provide  
31 for adjustment of the pay out and recovery of the

1 lift wire by referring to the motion of the load  
2 itself that is suspended by the lift wire.

3

4 Certain embodiments take account of the actual  
5 movement of the load and compensate for this by  
6 control of the winch. Certain embodiments of the  
7 present invention provide a heave compensation  
8 system that models the dynamics of the whole system,  
9 including the winch, the lift wire and the load  
10 itself.

11

12 Certain embodiments of the present invention offer a  
13 heave compensation system that can be used in  
14 greater water depths than conventional systems, and  
15 can also be used in shallow water and deeper water.  
16 Certain embodiments of the present invention  
17 compensate for the resonant behaviour of the load.  
18 Certain embodiments allow the operator to accurately  
19 control the height of the load by compensating for  
20 or eliminating oscillations in the movement of the  
21 load caused by movement of the vessel.

22

23 Certain embodiments provide a system that is capable  
24 of providing safe and stable handling of loads,  
25 particularly at increased water depths when compared  
26 to conventional systems.

27

28 Certain embodiments of the present invention offer a  
29 heave compensation system that includes a system  
30 that is capable of neutralising (e.g. damping) the  
31 effects of resonance of the load. Certain  
32 embodiments are capable of neutralising the

1 resonance effects that are already in evidence  
2 (lagging), but certain embodiments are also capable  
3 of predicting the onset of resonance and thus  
4 respond to these before they occur (leading).

5  
6 Certain embodiments provide a heave compensation  
7 system and a resonance damper/neutraliser. A  
8 further system is generally included that responds  
9 to normal operator commands e.g. for the load to be  
10 lifted, lowered or remain stationary.

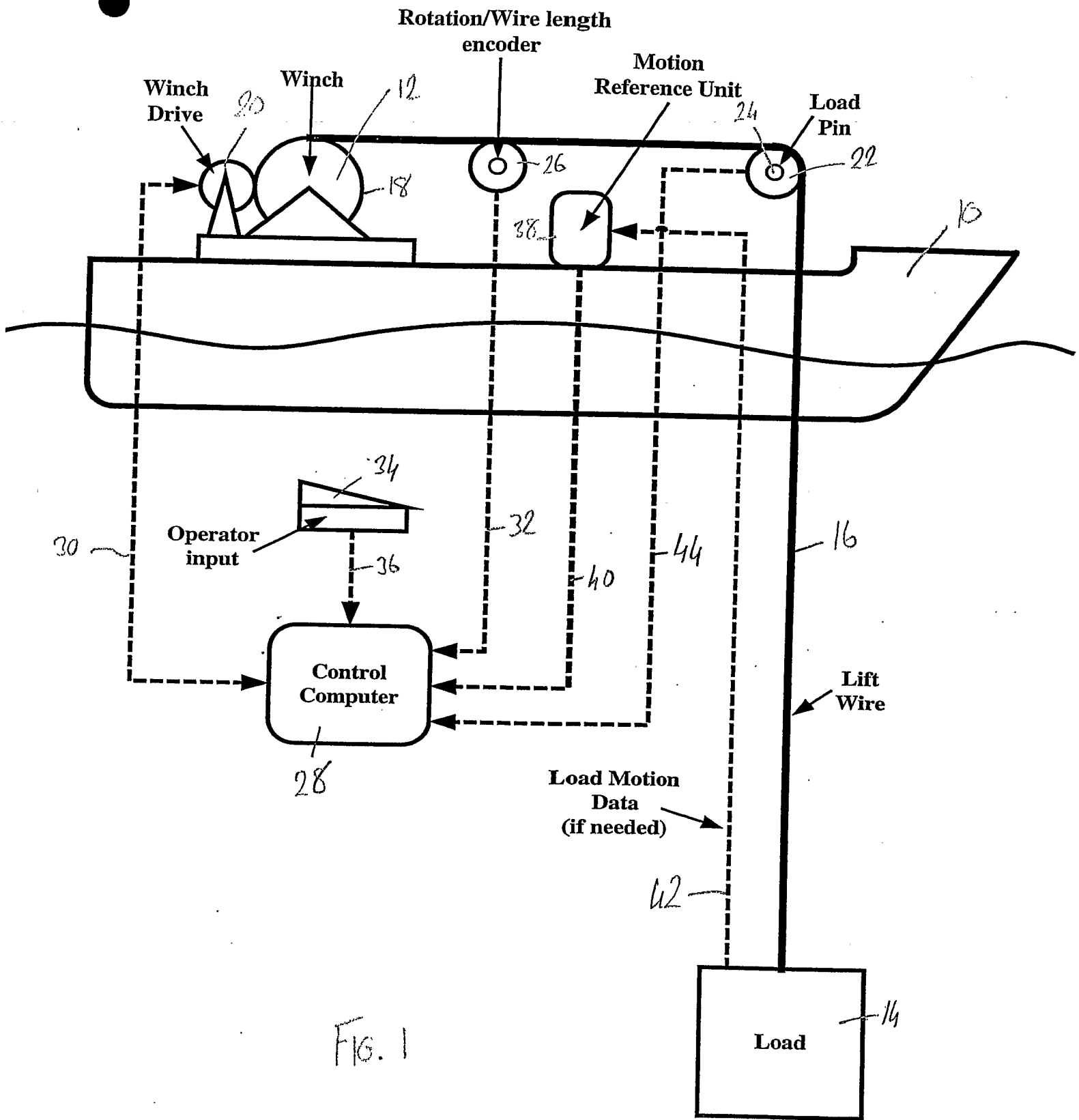
11  
12 Modifications and improvements may be made to the  
13 foregoing without departing from the scope of the  
14 present invention. For example, the control  
15 computer has been described as being electrically  
16 coupled to various other components using electrical  
17 cables, but the couplings could be via fibre optic  
18 or other transmission or telemetry systems (e.g. by  
19 radio etc).

20  
21 In a further alternative embodiment, it is possible  
22 to monitor the strain or tension on the lift wire  
23 other than by use of the load applied to the load  
24 pin. For example, an in-line strain gauge could be  
25 used to monitor the strain or tension on the lift  
26 wire direct. This could be provided at any suitable  
27 location (e.g. at the winch, the sheave etc.).

28  
29 In a further modification, it will be apparent that  
30 the foregoing description refers to adjustment of  
31 the winch drive to facilitate changes in the pay out  
32 and recovery rates of the lift wire. However, a

1 cable take-up device or other system that is capable  
2 of changing the pay out and recovery rates could be  
3 used. In one embodiment, a cable take-up device can  
4 be interposed between the winch and the over-  
5 boarding sheave. The cable length adjustments would  
6 generally be achieved electro-hydraulically, but an  
7 all-electric or other system could be used.

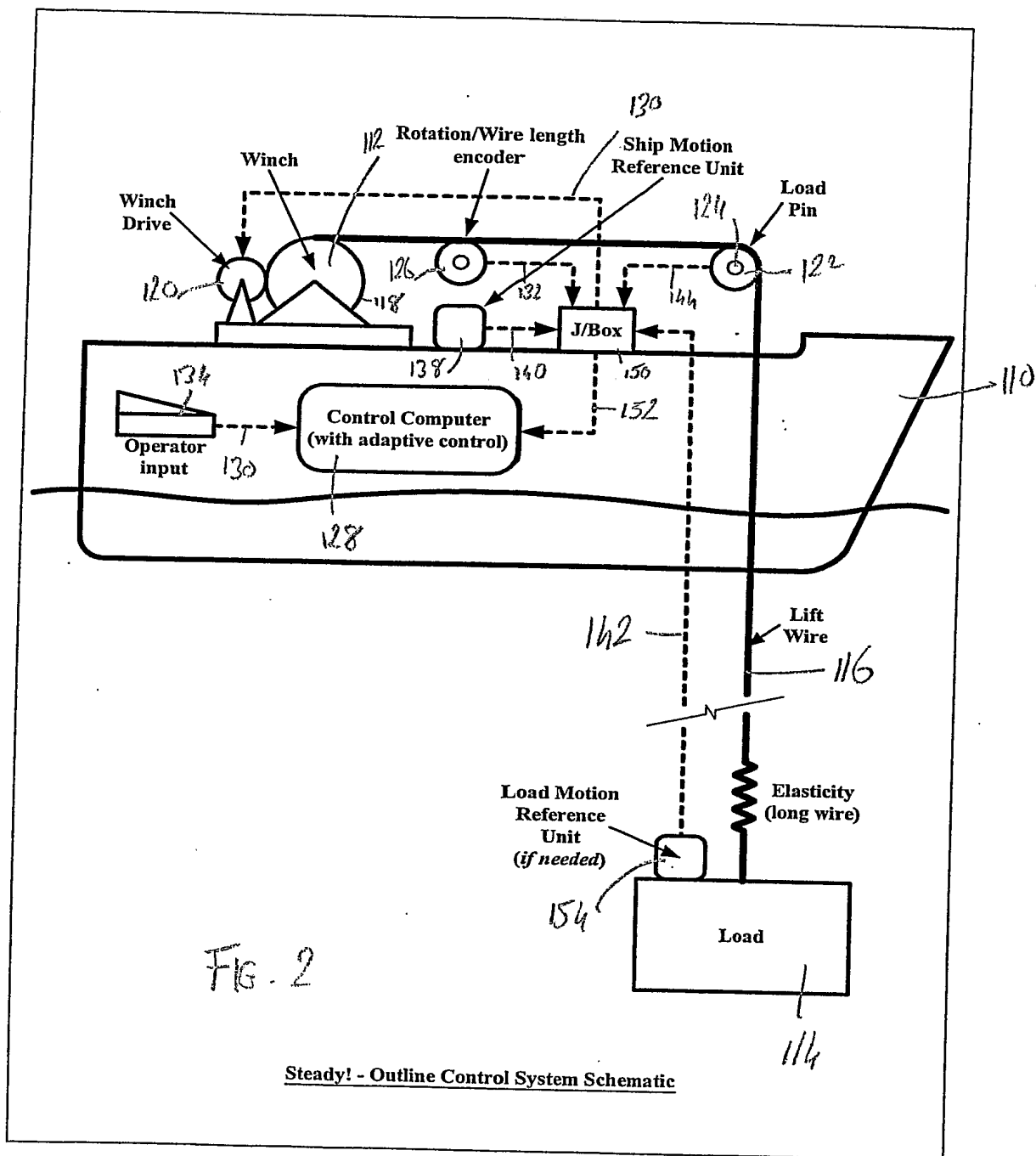
8  
9 It should be noted that the foregoing ignores motion  
10 of the lift wire suspension point in the horizontal  
11 plane as the load is generally a considerable  
12 distance from this point. Consequently, any effects  
13 will be insignificant and/or slow and easily  
14 accommodated.



Steady! - Control System Schematic









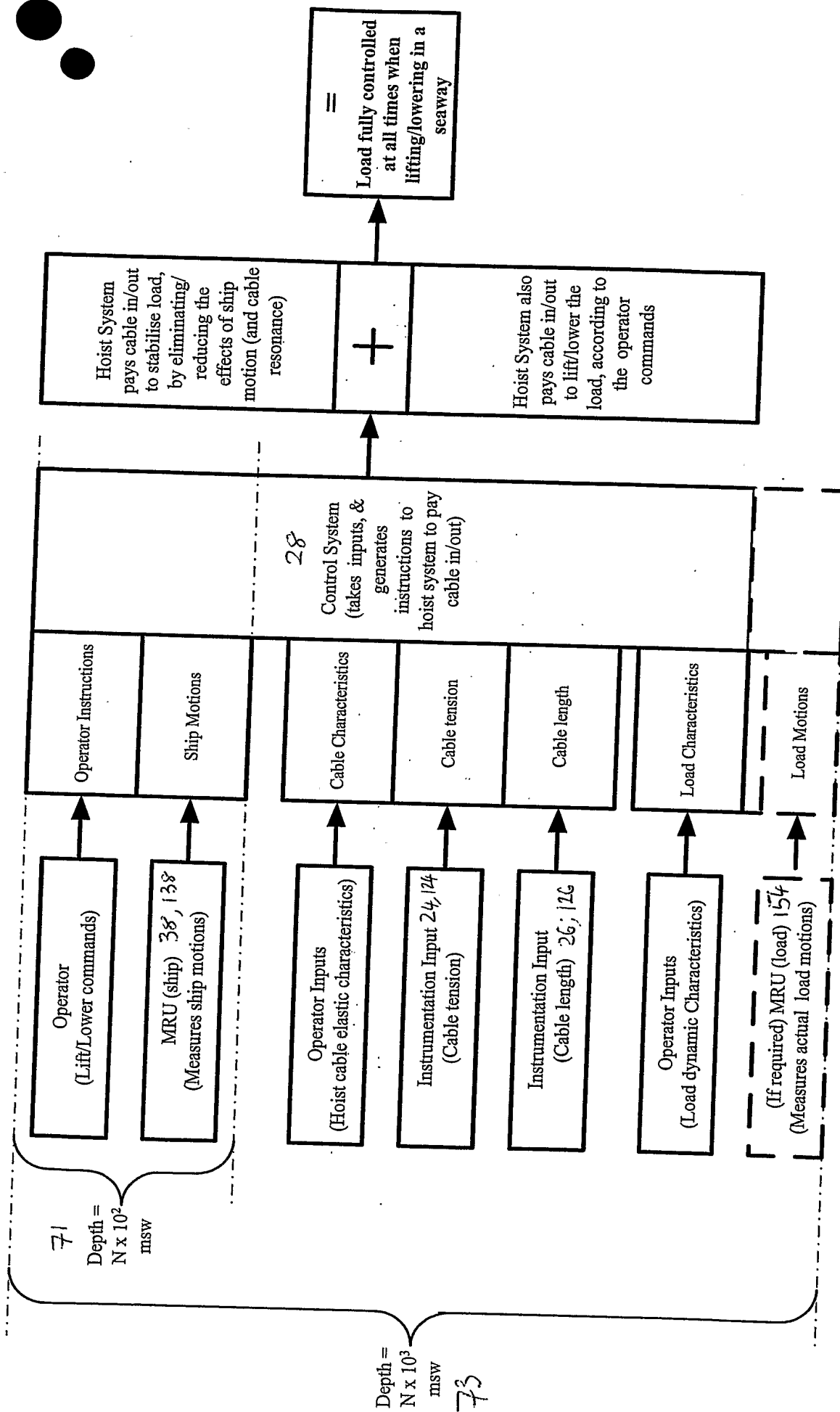


Fig.3.

Load Stabilisation - Block Diagram - Outline Control Requirements versus Depth

